

1.2 METAL CASTING

Introduction

Virtually nothing moves, turns, rolls, or flies without the benefit of cast metal products. The metal casting industry plays a key role in all the major sectors of our economy. There are castings in locomotives, cars, trucks, aircraft, office buildings, factories, schools, and homes. Figure 1.3 shows some metal cast parts.

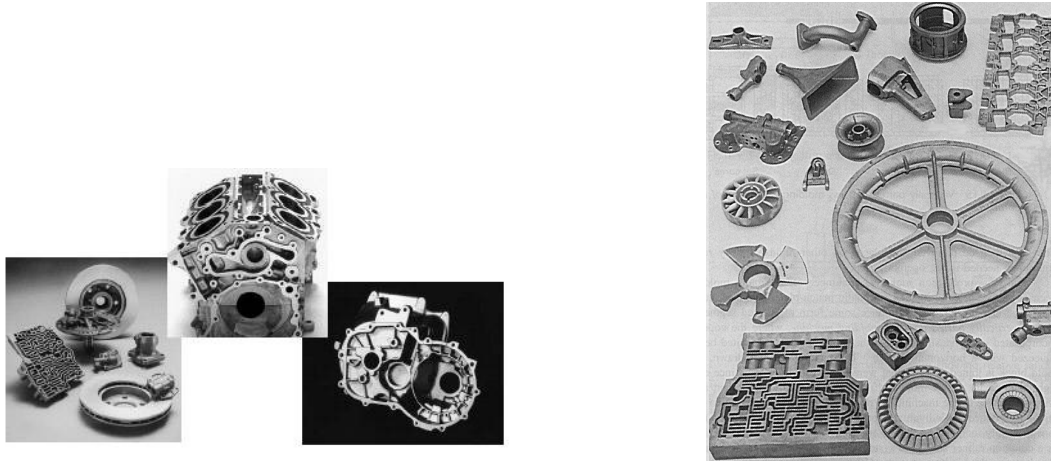
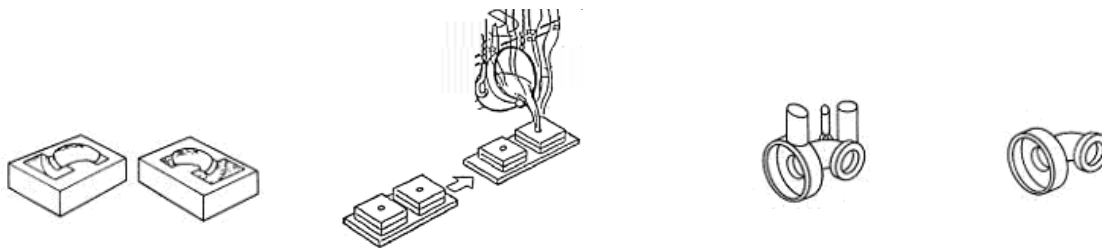


Fig. 1.3: Metal Cast parts

Metal Casting is one of the oldest materials shaping methods known. Casting means pouring molten metal into a mold with a cavity of the shape to be made, and allowing it to solidify. When solidified, the desired metal object is taken out from the mold either by breaking the mold or taking the mold apart. The solidified object is called the casting. By this process, intricate parts can be given strength and rigidity frequently not obtainable by any other manufacturing process. The mold, into which the metal is poured, is made of some heat resisting material. Sand is most often used as it resists the high temperature of the molten metal. Permanent molds of metal can also be used to cast products.



Refractory mold → pour liquid metal → solidify, remove → finish

Fig. 1.4: Simple casting process

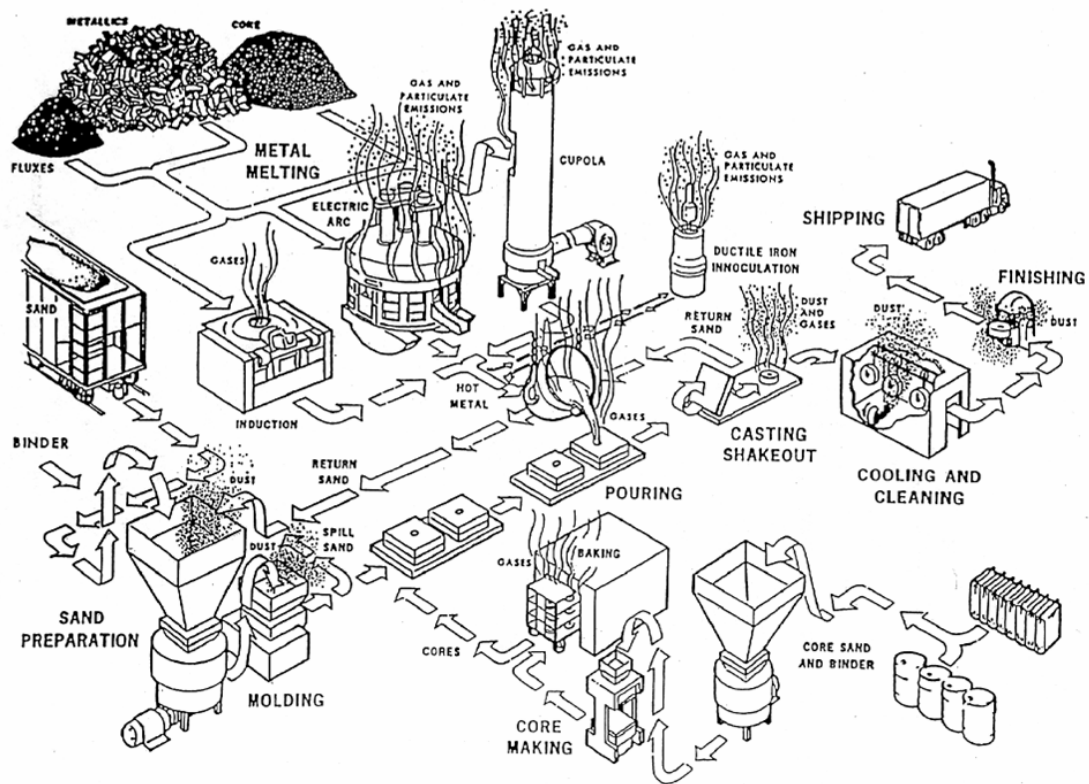


Fig. 1.5: Sand Casting process

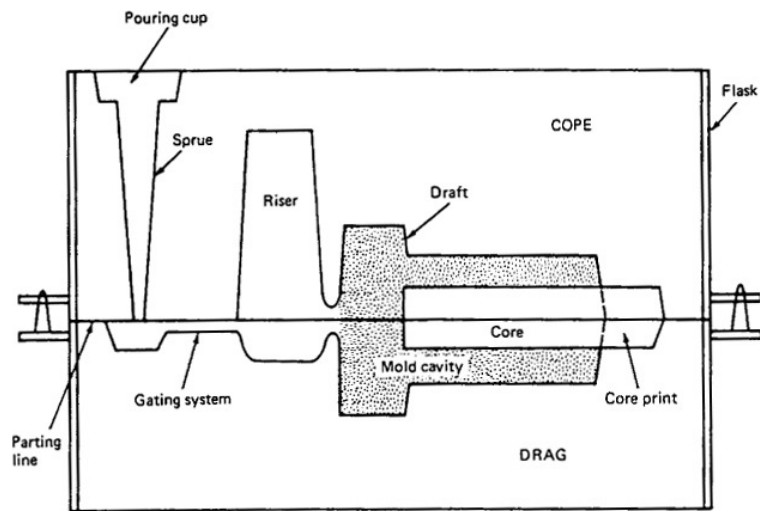


Fig. 1.6: Cross section of a sand mould

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Casting Terms

1. **Flask:** A metal or wood frame, without fixed top or bottom, in which the mold is formed. Depending upon the position of the flask in the molding structure, it is referred to by various names such as drag - lower molding flask, cope - upper molding flask, cheek - intermediate molding flask used in three piece molding.
2. **Pattern:** It is the replica of the final object to be made. The mold cavity is made with the help of pattern.
3. **Parting Line:** This is the dividing line between the two molding flasks that makes up the mold.
4. **Bottom Board:** This is a board normally made of wood which is used at the start of the mould making. The pattern is first kept on the bottom board, sand is sprinkled on it and then the ramming is done in the drag.
5. **Molding Sand:** Sand, which binds strongly without losing its permeability to air or gases. It is a mixture of silica sand, clay and moisture in appropriate proportions.
6. **Facing Sand:** The small amount of carbonaceous material sprinkled on the inner surface of the mold cavity to give a better surface finish to the castings.
7. **Backing Sand:** it is what constitutes most of the refractory material found in the mould. This is made up of used and burnt sand.
8. **Core:** A separate part of the mold, made of sand and generally baked, which is used to create openings and various shaped cavities in the castings.
9. **Pouring basin:** A small funnel shaped cavity at the top of the mold into which the molten metal is poured.
10. **Sprue:** The passage through which the molten metal, from the pouring basin, reaches the mold cavity. In many cases it controls the flow of metal into the mold.
11. **Runner:** The channel through which the molten metal is carried from the sprue to the gate.
12. **Gate:** A channel through which the molten metal enters the mold cavity.
13. **Chaplets:** Chaplets are used to support the cores inside the mold cavity to take care of its own weight and overcome the metallostatic force.
14. **Chill:** These are metallic objects which are placed in the mould to increase the cooling rate of castings to provide uniform or desired cooling rate.
15. **Riser:** A column of molten metal placed in the mold to feed the castings as it shrinks and solidifies. Also known as "feed head".
16. **Vent:** Small opening in the mold to facilitate escape of air and gases.

Steps in Making Sand Castings

There are six basic steps in making sand castings:

1. Patternmaking
2. Core making
3. Molding
4. Melting and pouring
5. Cleaning

Pattern Making

The pattern is a physical model of the casting used to make the mold. The mold is made by packing some readily formed aggregate material, such as molding sand, around the pattern. When the pattern is withdrawn, its imprint provides the mold cavity, which is ultimately filled with metal to become the casting. If the casting is to be hollow, as in the case of pipe fittings, additional patterns, referred to as cores are used to form these cavities

Core Making

Cores are forms, usually made of sand, which are placed into a mold cavity to form the interior surfaces of castings. Thus the void space between the core and mold-cavity surface is what eventually becomes the casting.

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Molding

Molding consists of all operations necessary to prepare a mold for receiving molten metal. Molding usually involves placing a molding aggregate around a pattern held with a supporting frame, withdrawing the pattern to leave the mold cavity, setting the cores in the mold cavity and finishing and closing the mold.

Melting and Pouring

The preparation of molten metal for casting is referred to simply as melting. Melting is usually done in a specifically designated area of the foundry, and the molten metal is transferred to the pouring area where the molds are filled.

Cleaning

Cleaning refers to all operations necessary to the removal of sand, scale, and excess metal from the casting. Burned-on sand and scale are removed to improve the surface appearance of the casting. Excess metal, in the form of fins, wires, parting line fins, and gates, is removed. Inspection of the casting for defects and general quality is performed.

Pattern

The pattern is the principal tool during the casting process. It is the replica of the object to be made by the casting process, with some modifications. The main modifications are the addition of pattern allowances, and the provision of core prints. If the casting is to be hollow, additional patterns called cores are used to create these cavities in the finished product. The quality of the casting produced depends upon the material of the pattern, its design, and construction. The costs of the pattern and the related equipment are reflected in the cost of the casting. The use of an expensive pattern is justified when the quantity of castings required is substantial.

Functions of the Pattern

1. A pattern prepares a mold cavity for the purpose of making a casting.
2. A pattern may contain projections known as core prints if the casting requires a core and need to be made hollow.
3. Runner, gates, and risers used for feeding molten metal in the mold cavity may form a part of the pattern.
4. Patterns properly made and having finished and smooth surfaces reduce casting defects.
5. A properly constructed pattern minimizes the overall cost of the castings.

Pattern Material

Patterns may be constructed from the following materials. Each material has its own advantages, limitations, and field of application. Some materials used for making patterns are: wood, metals and alloys, plastic, plaster of Paris, plastic and rubbers, wax, and resins. To be suitable for use, the pattern material should be:

1. Easily worked, shaped and joined
2. Light in weight
3. Strong, hard and durable
4. Resistant to wear and abrasion
5. Resistant to corrosion, and to chemical reactions
6. Dimensionally stable and unaffected by variations in temperature and humidity
7. Available at low cost

The usual pattern materials are wood, metal, and plastics. The most commonly used pattern material is wood, since it is readily available and of low weight. Also, it can be easily shaped and is relatively cheap. The main disadvantage of wood is its absorption of moisture, which can cause distortion and dimensional changes. Hence, proper seasoning and upkeep of wood is almost a pre-requisite for large-scale use of wood as a pattern material. Choice of pattern material depends essentially on the size of the casting, the number of castings to be made from the pattern, and the dimensional accuracy required. For very large castings, wood may be the only practical pattern material. Moulding sand being highly abrasive for large scale production, wood may not be suitable as a pattern material and one may have to opt for metal patterns. Because of their durability and smooth surface finish, metals such as aluminium and aluminium alloys, white metal, cast iron, steel, brass, bronze, lead alloys are most commonly used as pattern materials.

Plastics are also used as pattern materials because of their low weight, easier formability, smooth surfaces and durability. They don't absorb moisture and are dimensionally stable and can be cleaned easily.

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The making of a plastic pattern can be done in sand clay moulds or moulds made of plaster of paris. The most generally used plastics are cold setting epoxy resins with suitable fillers. With a proper combination it is possible to obtain a no shrink plastic material and as such double shrinkage allowances may not be required. Polyurethane foam (PUF), which is light and easily formed, can be used for light duty work for small number of castings.

Pattern Allowances

Pattern allowance is a vital feature as it affects the dimensional characteristics of the casting. Thus, when the pattern is produced, certain allowances must be given on the sizes specified in the finished component drawing so that a casting with the particular specification can be made. The selection of correct allowances greatly helps to reduce machining costs and avoid rejections. The allowances usually considered on patterns and core boxes are as follows:

1. Shrinkage or contraction allowance
2. Draft or taper allowance
3. Machining or finish allowance
4. Distortion or camber allowance
5. Rapping allowance

Shrinkage or Contraction Allowance

All most all cast metals shrink or contract volumetrically on cooling. The metal shrinkage is of two types:

i. *Liquid Shrinkage*: It refers to the reduction in volume when the metal changes from liquid state to solid state at the solidus temperature. To account for this shrinkage; risers, which feed the liquid metal to the casting, are provided in the mold.

ii. *Solid Shrinkage*: It refers to the reduction in volume caused when metal loses temperature in solid state. To account for this, shrinkage allowance is provided on the patterns. The rate of contraction with temperature is dependent on the material. For example steel contracts to a higher degree compared to aluminum. To compensate the solid shrinkage, a shrink rule must be used in laying out the measurements for the pattern. A shrink rule for cast iron is 10.5 mm longer per meter than a standard rule. If a gear blank of 250 mm in diameter was planned to produce out of cast iron, the shrink rule in measuring it 250 mm would actually measure 250 plus $10.5 / 4$ mm, thus compensating for the shrinkage. The various rate of contraction of various materials are given in Table I.

Material	Dimension , mm	Shrinkage allowance (mm/m)
Grey Cast Iron	Up to 600 600 to 1200 over 1200	10.5 8.5 7.0
White Cast Iron		16.0 to 23.0
Ductile Iron		8.3 to 10.4
Malleable Iron		2.6 to 11.8
Plain Carbon Steel	Up to 600 600 to 1800 over 1800	21 16 13
Chromium Steel		20
Manganese Steel		25.0 to 38.0
Aluminum		13
Magnesium		13
Copper		16
Brass		15.5
Bronze		15.5 to 22.0
Gun Metal		10.0 to 16.0
Lead		26

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Monel		20
Magnesium Alloy		16
White Metal		6
Zinc		10.0 to 15.0

Table I : Rate of Contraction of Various Metals

The shrinkage allowance is always to be added to the linear dimensions. Even in case of internal dimensions (e.g. internal diameters of cylinders), the material has a tendency to contract towards the centre and thus are to be increased.

Draft or Taper Allowance

By draft is meant the taper provided by the pattern maker on all vertical surfaces of the pattern so that it can be removed from the sand without tearing away the sides of the sand mold and without excessive rapping by the molder. Draft allowance varies with the complexity of the sand job. But in general inner details of the pattern require higher draft than outer surfaces. The amount of draft depends upon the length of the vertical side of the pattern to be extracted; the intricacy of the pattern; the method of molding; and pattern material. More draft needed to be provided for hand moulding compared to machine moulding. The draft is always provided as an extra metal over and above the original casting dimensions.

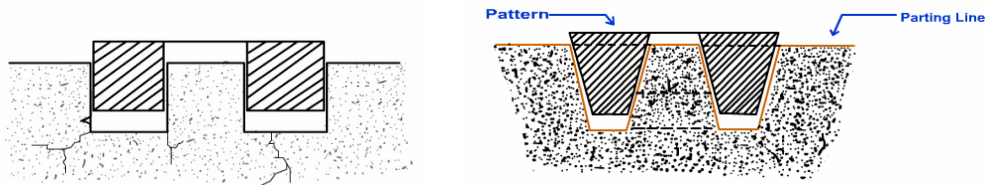


Fig. 1.7: Draft Allowance

Pattern material	Height of the given surface (mm)	Draft angle in degree (External surface)	Draft angle in degree (Internal surface)
Wood	Upto 20	3.00	3.00
	21 to 50	1.50	2.50
	51 to 100	1.00	1.50
	101 to 200	0.75	1.00
	201 to 300	0.50	1.00
	301 to 800	0.50	0.75
	801 to 2000	0.35	0.50
	Above 2000	---	0.25
Metal and plastic	Upto 20	1.50	3.00
	21 to 50	1.00	2.00
	51 to 100	0.75	1.00
	101 to 200	0.50	0.75
	201 to 300	0.50	0.75
	301 to 800	0.35	0.50

Table II: Suggested draft values for pattern

Finish or Machining Allowance

The finish and accuracy achieved in sand casting are generally poor and therefore when the casting is functionally required to be of good surface finish or dimensionally accurate, it is generally achieved by subsequent machining. Machining or finish allowances are therefore added in the pattern dimension. Also, ferrous materials would have scales on the skin which are to be removed by cleaning.

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Finish allowance is the amount the dimensions on a casting are made over size to provide stock for machining. It is influenced by the metal, the casting design, the finish required, the complexity of surface details, the method of casting and cleaning. Since machining allowance provided would ultimately have to be removed by machining, therefore the cost of providing additional machining allowance should be carefully examined before finalizing. One way of reducing the machining allowance is to keep entire casting in the drag flask such that dimensional variation and other defects due to parting plane are reduced to a minimum. This allowance may range from 2 to 20 mm.

Dimension, mm	Machining Allowance, mm		
	Bore	Surface	Cope Side
Cast Iron			
Up to 300	3.0	3.0	5.5
301 to 500	5.0	4.0	6.0
501 to 900	6.0	5.0	6.0
Cast Steel			
Up to 300	3.0	3.0	6.0
301 to 500	6.0	5.5	7.0
501 to 900	7.0	6.0	9.0
Non Ferrous			
Up to 300	2.0	1.0	2.0
301 to 500	2.5	1.5	3.0
501 to 900	3.0	2.5	3.0

Table III: Suggested Machining Allowance values for pattern

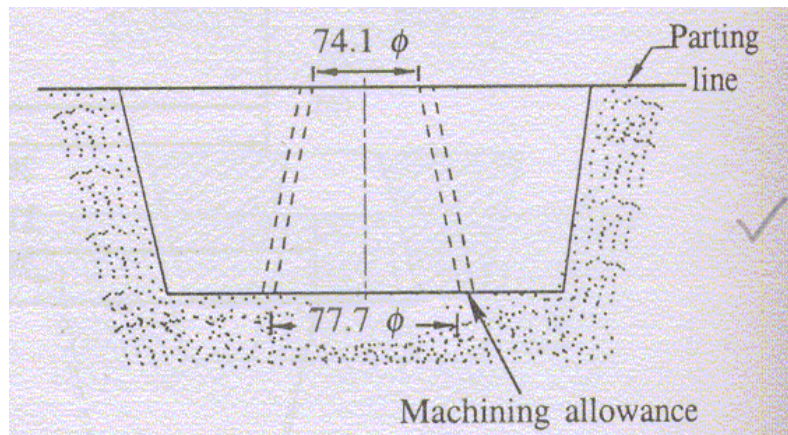


Fig. 1.8: Machining Allowance

Distortion Allowance

A metal when it has just solidified, is very weak and therefore is likely to be distortion prone. Sometimes castings get distorted, during solidification, due to their typical shape. For example, if the casting has the form of the letter U, V, T, L or long flat portions etc. it will tend to contract at the closed end causing the vertical legs to look slightly inclined. This can be prevented by making the legs of the U, V, T, or L shaped pattern converge slightly (inward) so that the casting after distortion will have its sides vertical. This can be done by trial and error basis to get the distortion amount. Another way to take care of this phenomenon is to make extra material provision for reducing the distortion. The distortion in casting may occur due to internal stresses. These internal stresses are caused on account of unequal cooling of different section of the casting and hindered contraction. Measure taken to prevent the distortion in casting includes:

- Modification of casting design
- Providing sufficient machining allowance to cover the distortion effect

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- Providing suitable allowance on the pattern called camber or distortion allowance(inverse reflection).

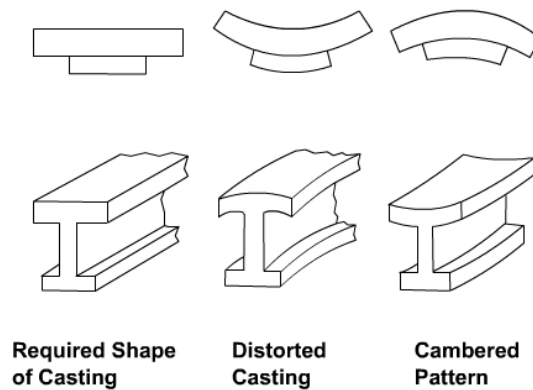


Fig. 1.9: Distortion in castings

Shake Allowance

Before the withdrawal from the sand mold, the pattern is rapped all around the vertical faces to enlarge the mold cavity slightly, which facilitate its removal. Since it enlarges the final casting made, it is desirable that the original pattern dimension should be reduced to account for this increase. There is no sure way of quantifying this allowance, since it is highly dependent on the foundry personnel practice involved. It is a negative allowance and is to be applied only to those dimensions that are parallel to the parting plane. One way of reducing this allowance is to increase the draft which can be removed during the subsequent machining.

Types of Patterns

There are various types of patterns depending upon the complexity of the job, the number of castings required and the moulding procedure adopted.

Single Piece Pattern

The one piece or single pattern is the most inexpensive of all types of patterns. This type of pattern is used only in cases where the job is very simple and does not create any withdrawal problems. It is also used for application in very small-scale production or in prototype development. This type of pattern is expected to be entirely in the drag and one of the surfaces is expected to be flat which is used as the parting plane. A gating system is made in the mold by cutting sand with the help of sand tools. If no such flat surface exists, the molding becomes complicated.

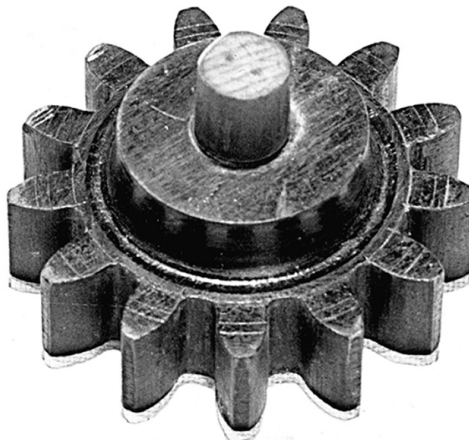


Fig. 1.10: Single piece pattern

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Split Pattern or Two Piece Pattern

Split or two piece pattern is most widely used type of pattern for intricate castings. It is split along the parting surface, the position of which is determined by the shape of the casting. One half of the pattern is molded in drag and the other half in cope. The two halves of the pattern must be aligned properly by making use of the dowel pins, which are fitted, to the cope half of the pattern. These dowel pins match with the precisely made holes in the drag half of the pattern.

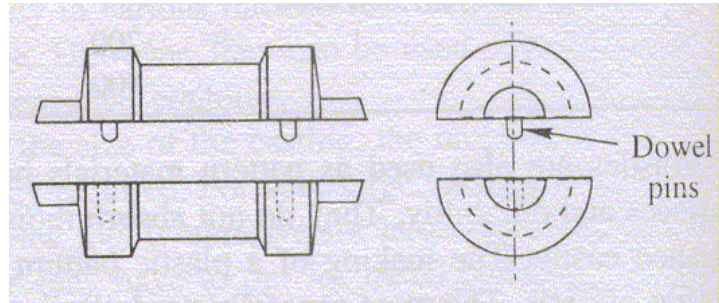


Fig. 1.11: Two piece pattern

Gated Pattern

This is an improvement over the simple pattern where the gating and runner system are integral with the pattern. This would eliminate the hand cutting of the runners and gates and help in improving the productivity of a moulder.

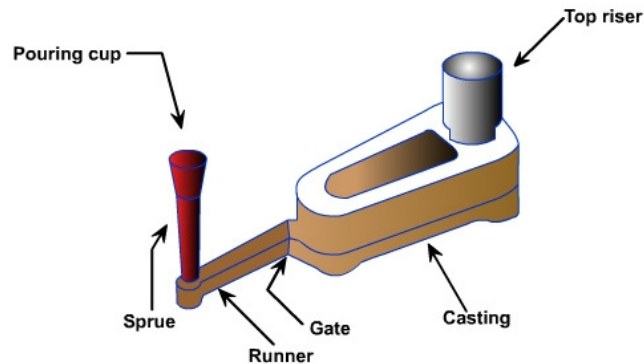


Fig. 1.12: A typical pattern attached with gating and risering system

Cope and Drag Pattern

These are similar to split patterns. In addition to splitting the pattern, the cope and drag halves of the pattern along with the gating and risering systems are attached separately to the metal or wooden plates along with the alignment pins. The cope and drag moulds may be produced using these patterns separately by two moulders but they can be assembled to form a complete mould. These types of patterns are used for castings which are heavy and inconvenient for handling as also for continuous production.

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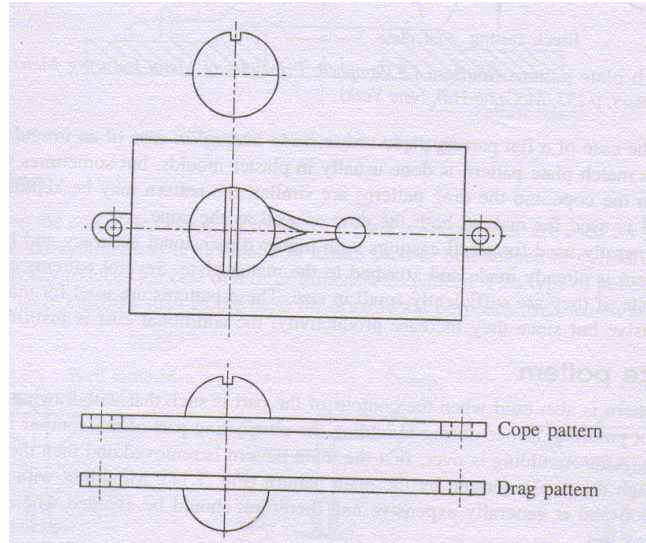


Fig. 1.13: Cope and Drag Pattern

Match Plate Pattern

Here the cope and drag patterns along with the gating and risering are mounted on a single matching plate on either side. On one side of the match plate the cope flask is prepared and on the other, the drag flask. After moulding when the match plate is removed, a complete mould with gating is obtained by joining the cope and the drag together. The complete pattern with match plate is entirely made of metal, usually aluminium for its light weight and machinability. But when dimensions are critical, the match plate may be made of steel with necessary case hardening of the critical wear points. The pattern and gating are either screwed to the match plate in the case of a flat parting plane or made integral in case of an irregular parting plane.

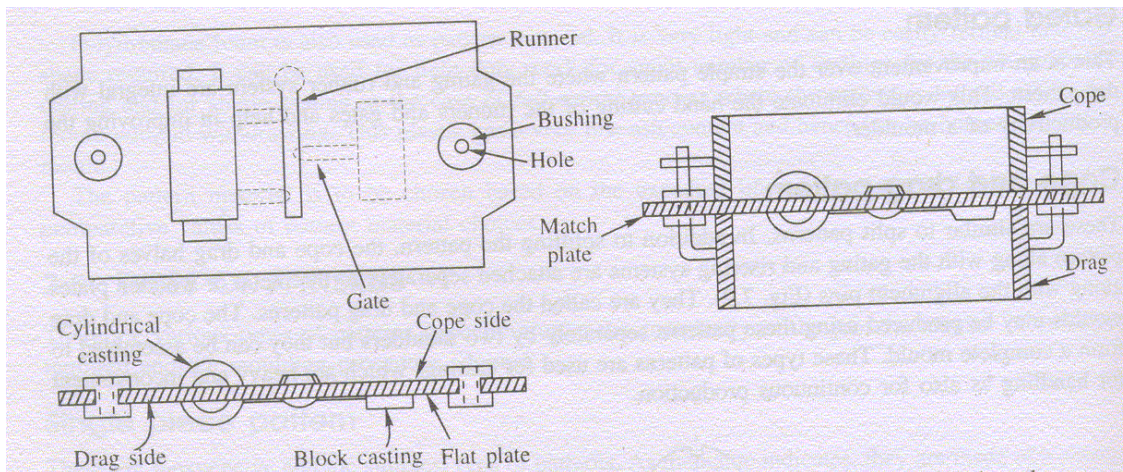


Fig. 1.14: Match Plate Pattern

These are generally used for small castings with higher dimensional accuracy and large production. Several patterns can be fixed to a single match plate, if they are sufficiently small in size. These are used for machine moulding.

Loose Piece Pattern

This type of pattern is used when the contour of the part is such that withdrawing the pattern from the mould is not possible. Hence during moulding the obstructing part of the contour is held as a loose piece by a wire. After moulding is over, first the main pattern is removed and then loose pieces are

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recovered through the gap generated by the main pattern. Moulding with loose pieces is a highly skilled job and is generally expensive and therefore, should be avoided wherever possible.

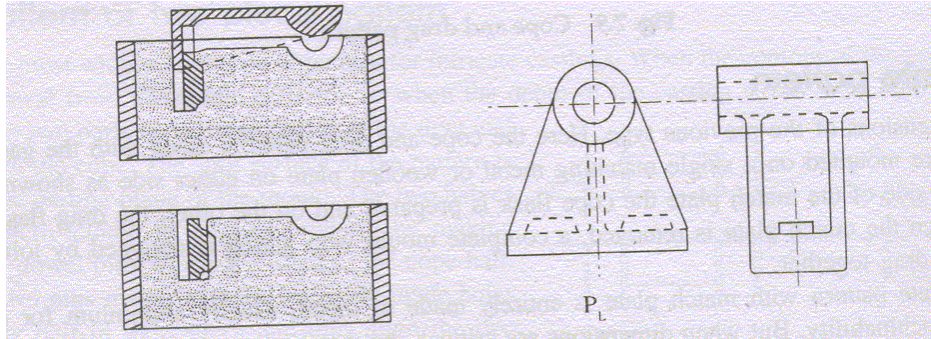


Fig. 1.15: Loose Piece Pattern

Follow Board Pattern

This type of pattern is adopted for those castings where there are some portions which are structurally weak and if not supported properly are likely to break under the force of ramming. Hence the bottom board is modified as a follow board to closely fit the contour of the weak pattern and thus support it during the ramming of the drag.

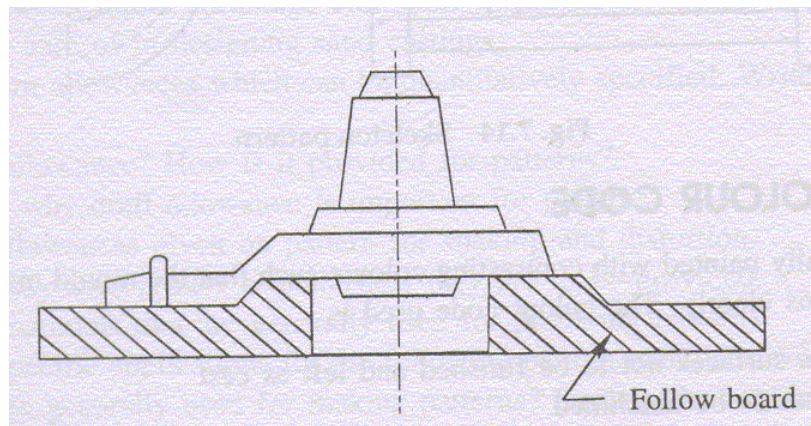


Fig. 1.16: Follow Board Pattern

Sweep Pattern

It is used to sweep the complete casting by means of a plane sweep. These are used for generating large shapes which are axi-symmetrical or prismatic in nature such as bell shaped or cylindrical. This greatly reduces the cost of a three dimensional pattern. It is suitable for very large castings such as the bells for ornamental purposes used which are generally cast in pit moulds.

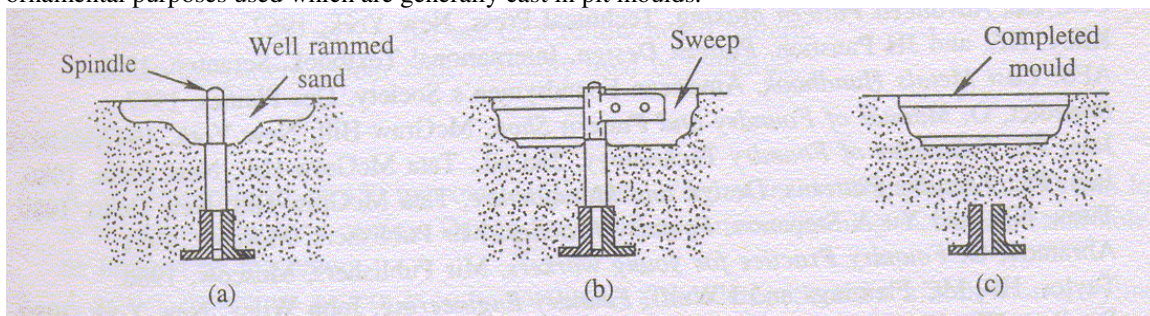


Fig. 1.17: Sweep Pattern

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Skeleton Pattern

It is made of strips of wood and is used for building the final pattern by packing sand around the skeleton. After packing the sand, the desired form is made with the help of a strickle. This type of pattern is useful for large castings, required in small quantities where large expense on complete wooden pattern is not justified.

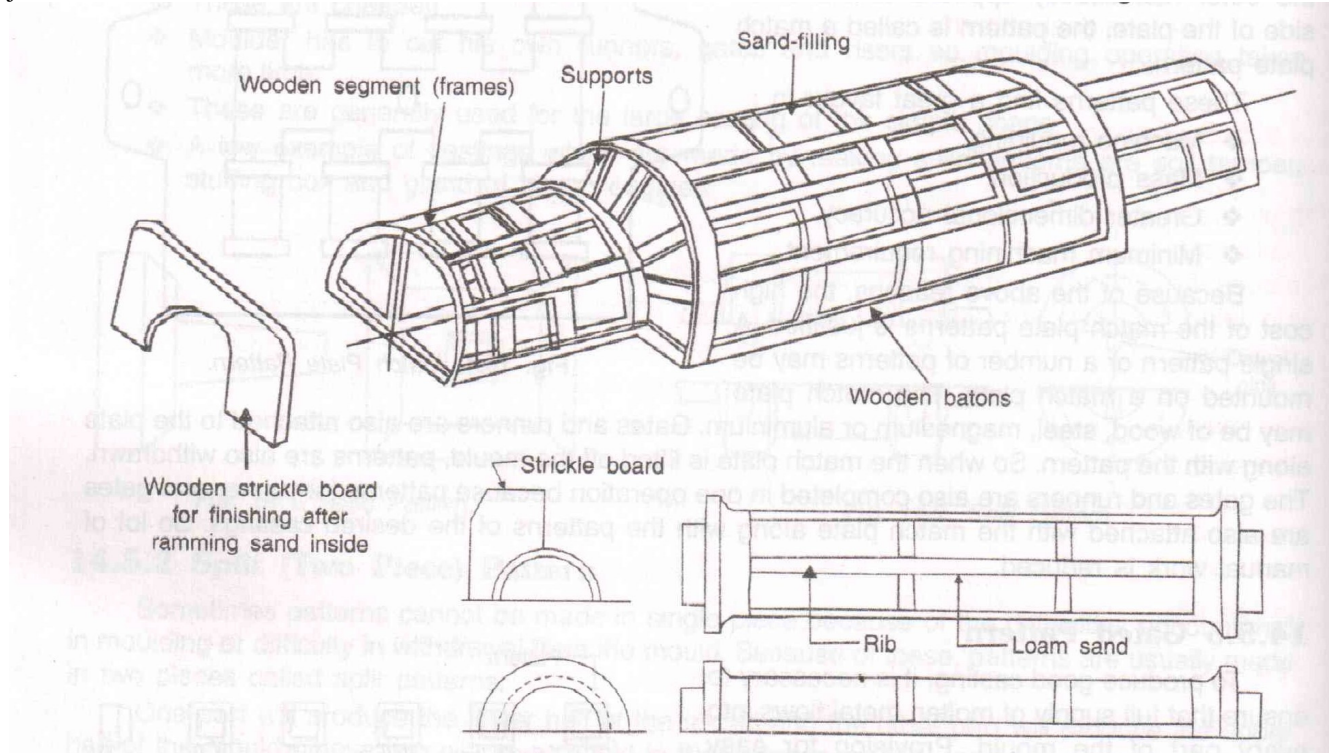


Fig. 1.18: Skeleton Pattern

Reference: 1. Manufacturing Technology by P.N.Rao, TMH, page 67-80
2. NPTEL website on Manufacturing Processes-I